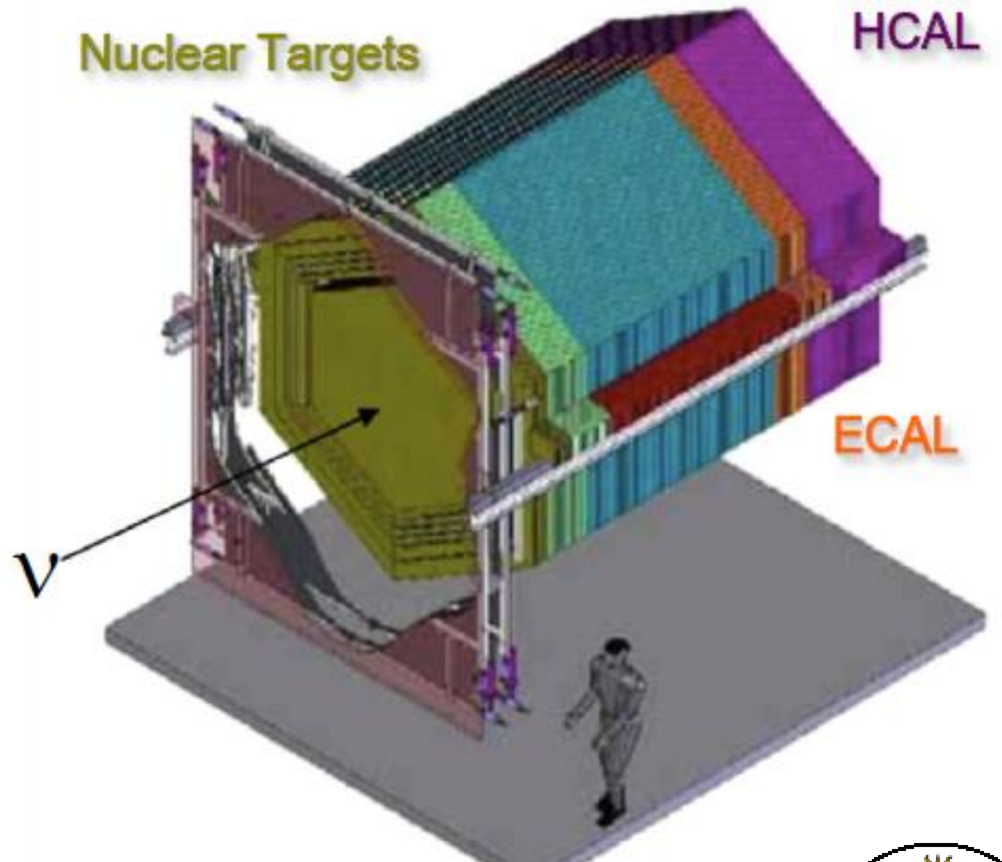
ν – N Deep Inelastic Scattring at MINERνA



NUFACT 15 RIO DE JANEIRO BRAZIL
AUGUST 10-15

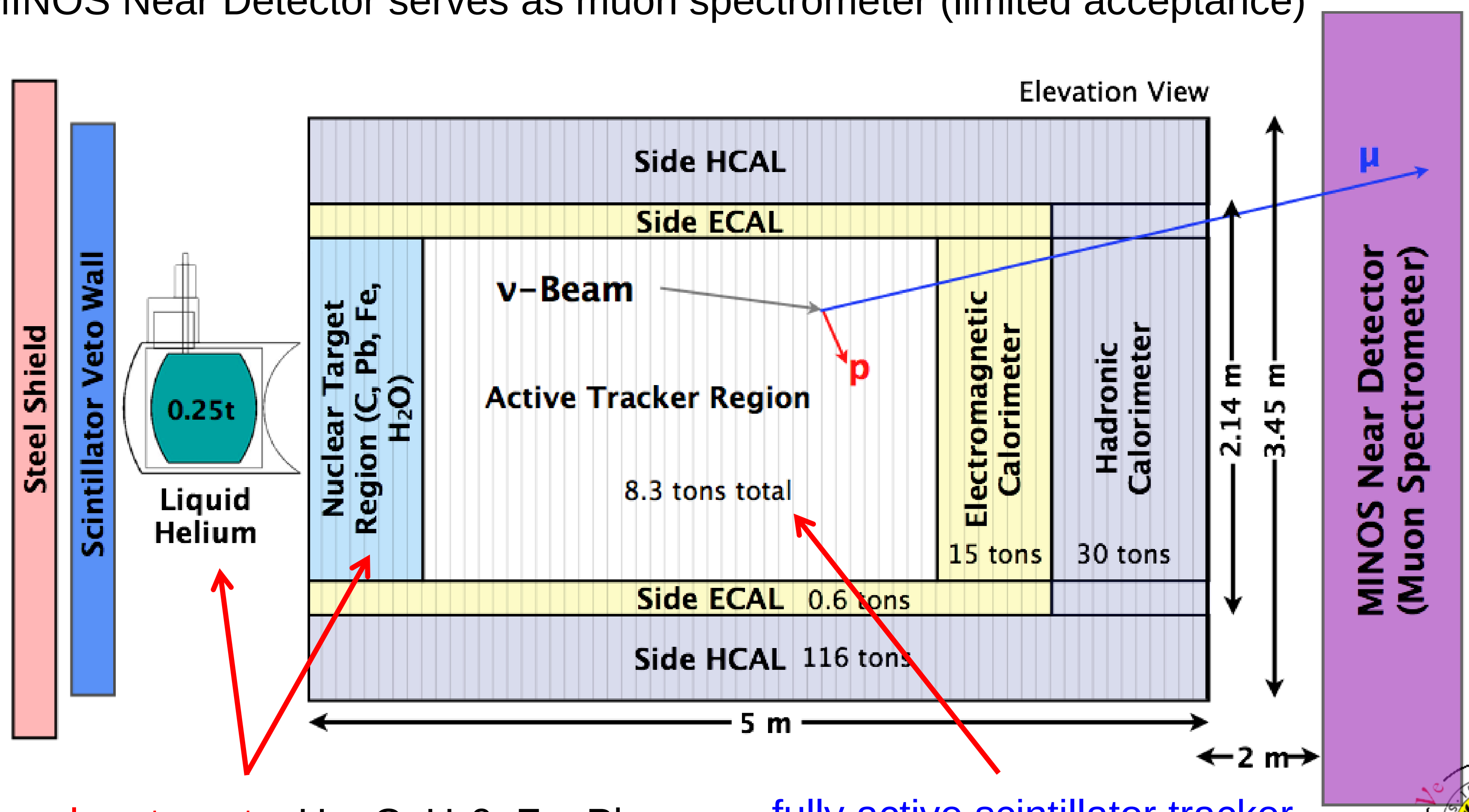
Alessandro Bravar
Université de Genève
for the MINERνA Collaboration

The MINERνA Detector

MINERνA, NIM A743 (2014) 130

120 plastic fine-grained scintillator modules stacked along the beam direction for tracking and calorimetry (~32k readout channels with MAPMTs)

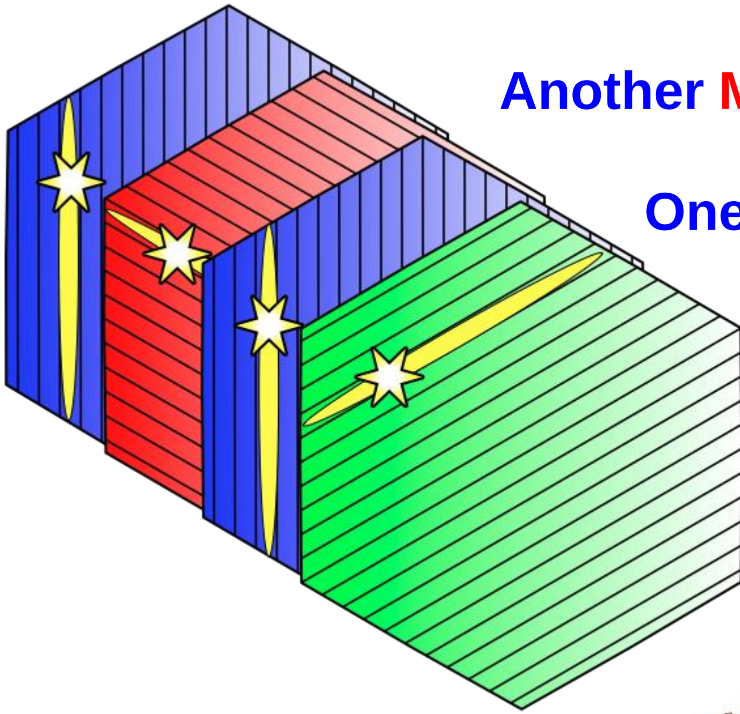
MINOS Near Detector serves as muon spectrometer (limited acceptance)

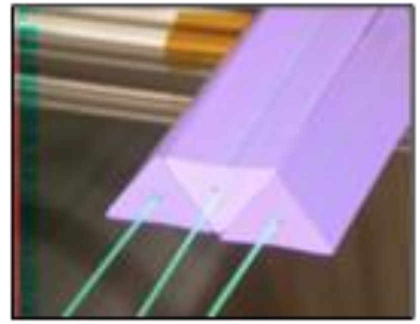


nuclear targets: He, C, $H_2$0, Fe, Pb
in the same neutrino beam

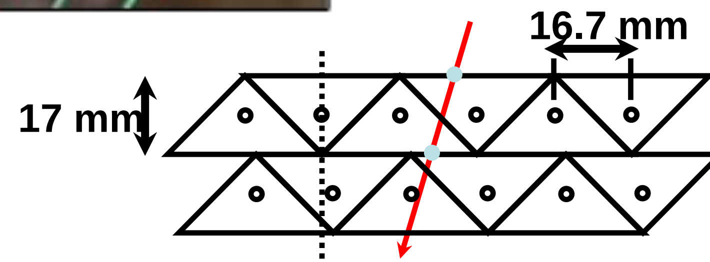
fully active scintillator tracker
(x/v and x/u modules)

Detector Technology

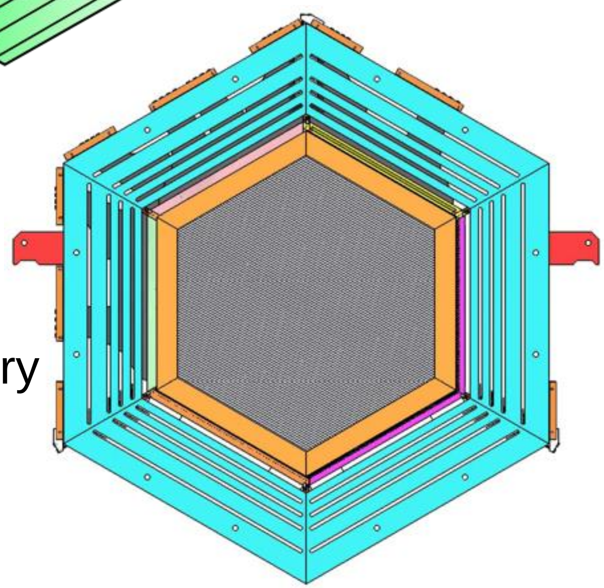


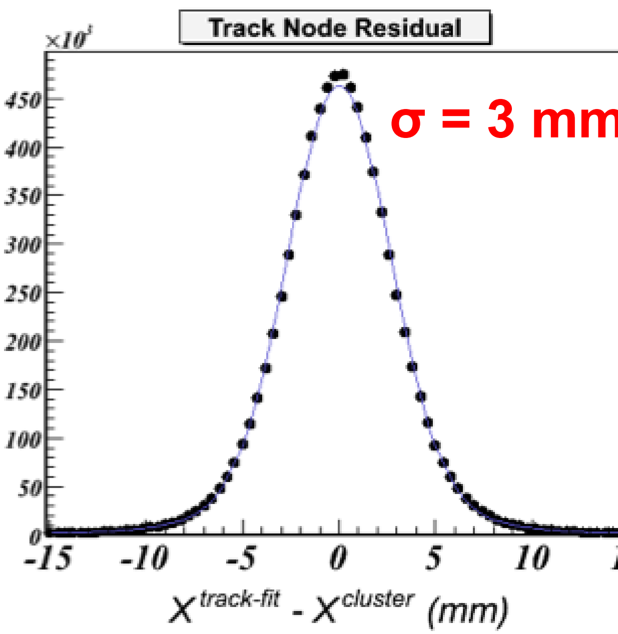


triangular scint. bars
with WLS fiber
and MAPMT readout



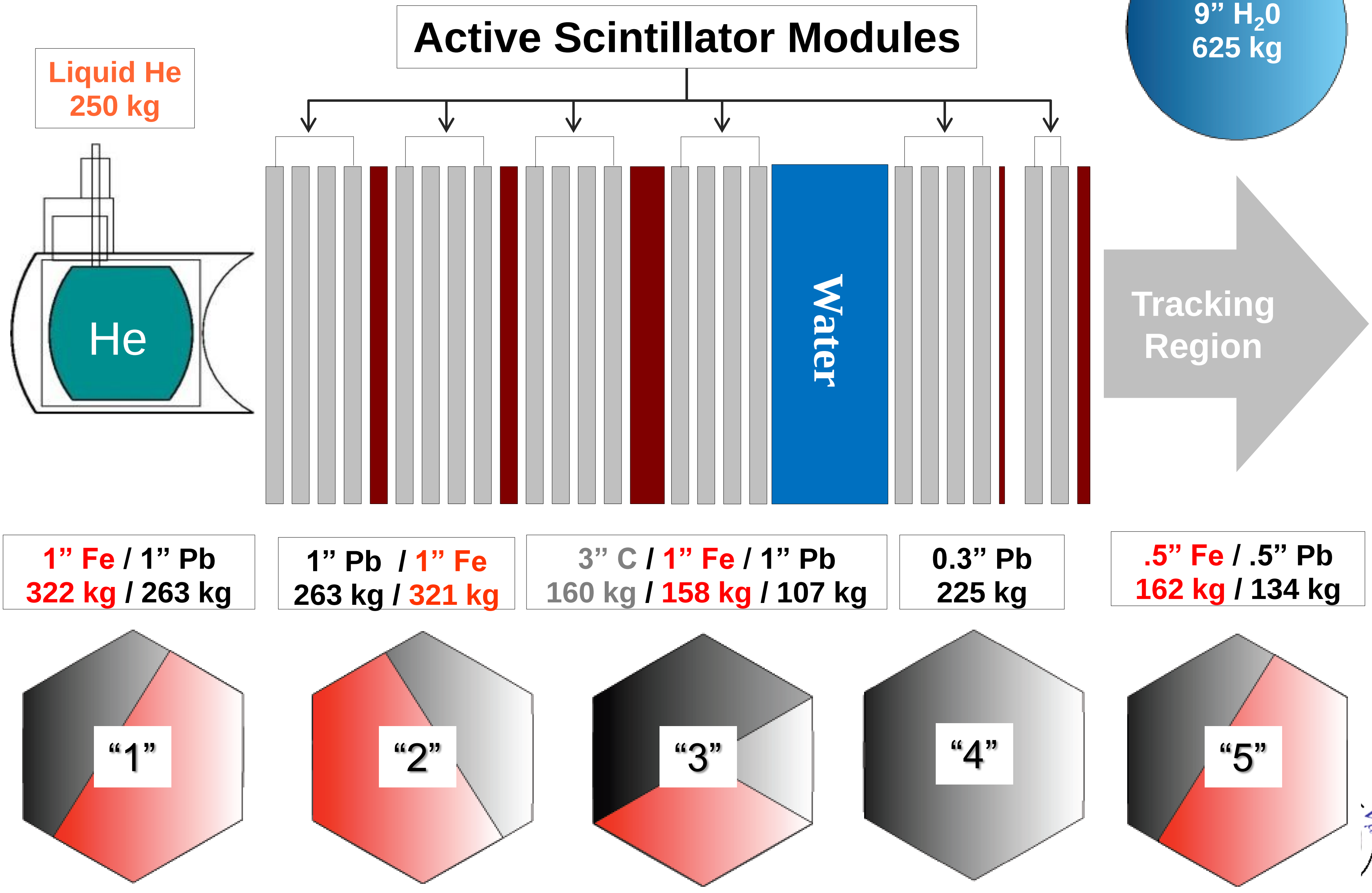
Charge sharing for improved position resolution (~3 mm) and alignment





Scintillator - tracking
Lead - EM calorimetry
Steel - hadronic calorimetry

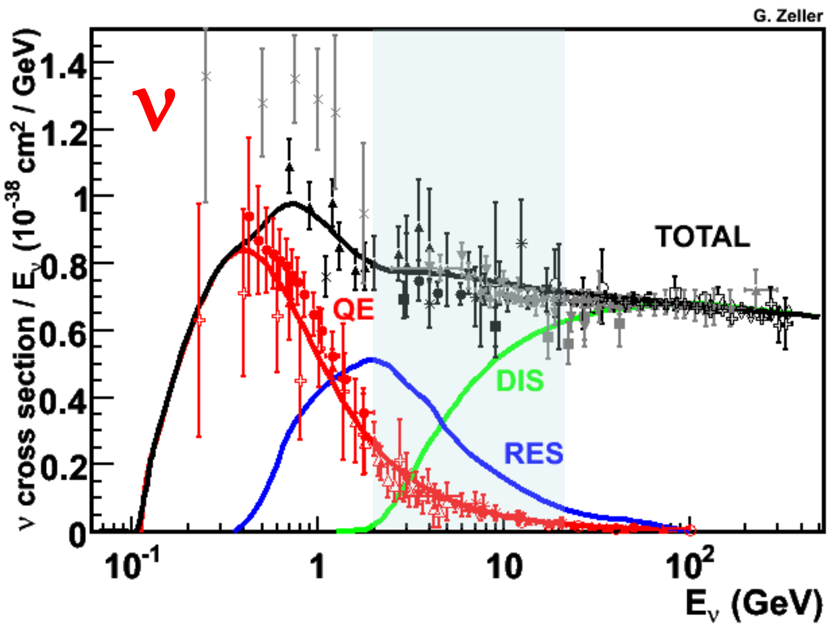
Nuclear Targets

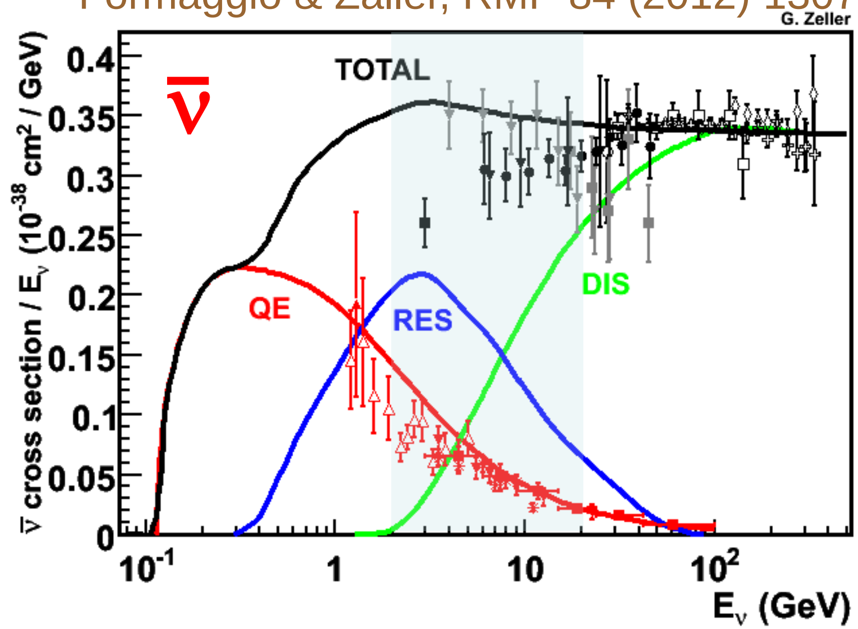


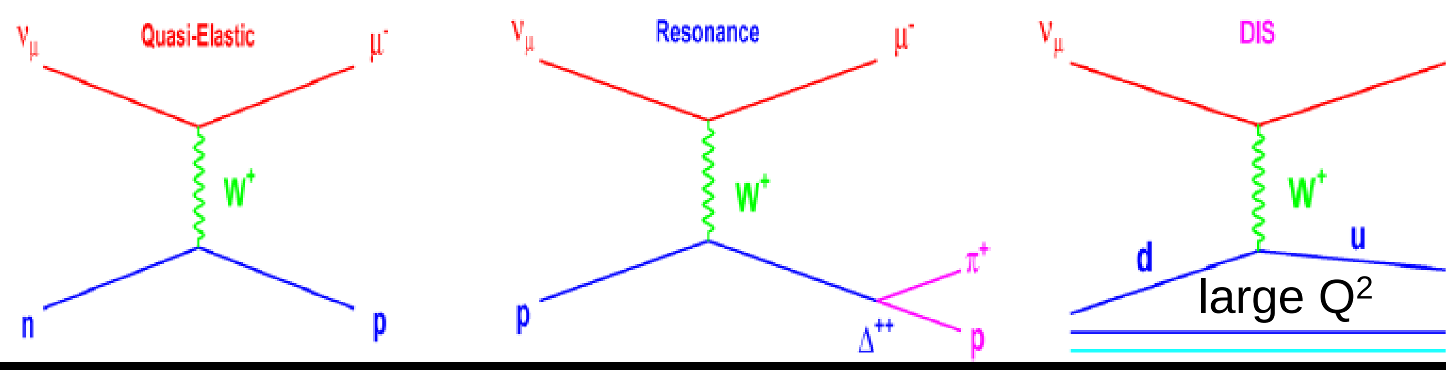
ν ×-sections

MINERνA measures ν – N interactions in the transition region from exclusive states to DIS

Formaggio & Zaller, RMP 84 (2012) 1307







elastic

inelastic

increasing E_ν, Q^2

Probing Nucleon Structure with Neutrinos

neutrinos – weak probe of nuclear (low E) and hadronic (high E) structure

Charged lepton scattering data show that quark distributions in nucleons bound in a nucleus are modified w.r.t. free nucleons (EMC effect, shadowing at low *x*, …)
PDFs of a nucleon within a nucleus are different from PDFs of a free nucleon

ν probes same quark flavors as charged leptons but with different "weights"

- ν's also sensitive to the axial piece of F_2
- ν's sensitive to xF_3 (changes sign between ν and anti-ν)
  - $\rightarrow$ expect different shape ?
  - $\rightarrow$ expect different behavior ?
  - $\rightarrow x \rightarrow 1$?
  - $\rightarrow$ is shadowing the same ?

Nuclear effects in neutrino (DIS) scattering are not well established, and have not been measured directly
experimental results to date have all involved one target material per experiment (Fe or Pb or …)

MINERνA attempts a systematic study of these effects using different A targets in the same detector exposed to the same neutrino beam

What Have We Observed with EM Probes ?

CERN COURIER

Apr 26, 2013

The EMC effect still puzzles after 30 years

Thirty years ago, high-energy muons at CERN revealed the first hints of an effect that puzzles experimentalists and theorists alike to this day.

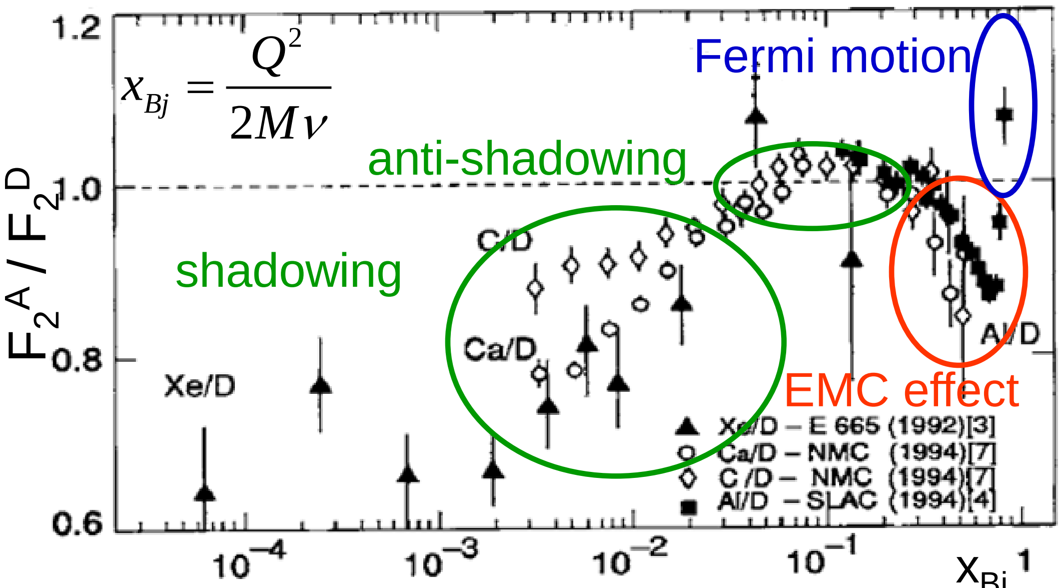
Bodek-Yang Model (2003)
for nuclear modifications
arXiv:hep-ex/0308007

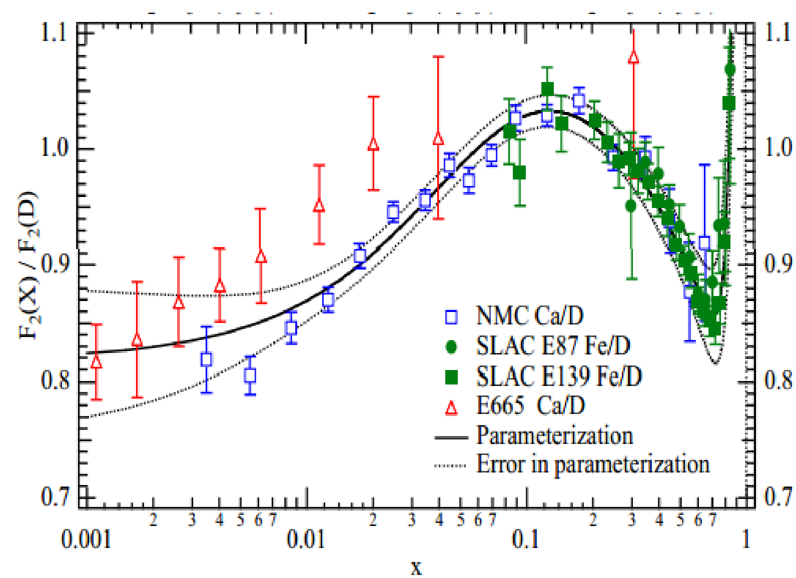
(Neutrino event generators rely on measurements from charged leptons)

Fit to charged lepton data

All nuclei have same modifications
All treated as isoscalar iron

A / D Ratio (e / μ DIS)





The EMC effect (valence region) does not shows a strong A dependence for F_2^A / F_2^D

Nuclear modification fit
for iron to deuterium ratio

CTEQ Predictions for MINERνA

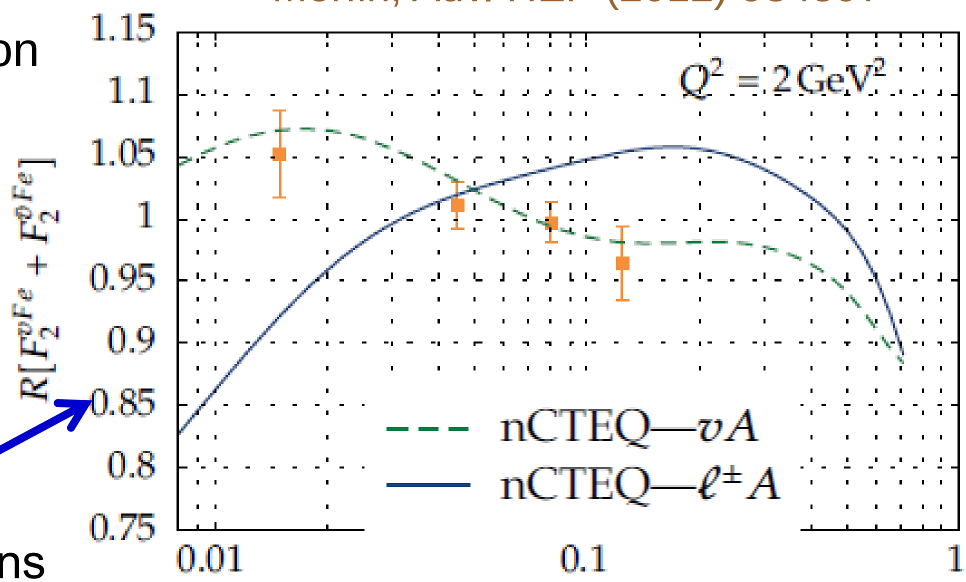
General strategy has been to adapt electron scattering effects into neutrino scattering theory
Neutrino event generators rely on measurements from charged leptons

CTEQ tries to fit for nuclear effects by
- comparing NuTeV structure functions on iron to predicted "n+p" structure functions
- comparing to predictions from charged lepton scattering

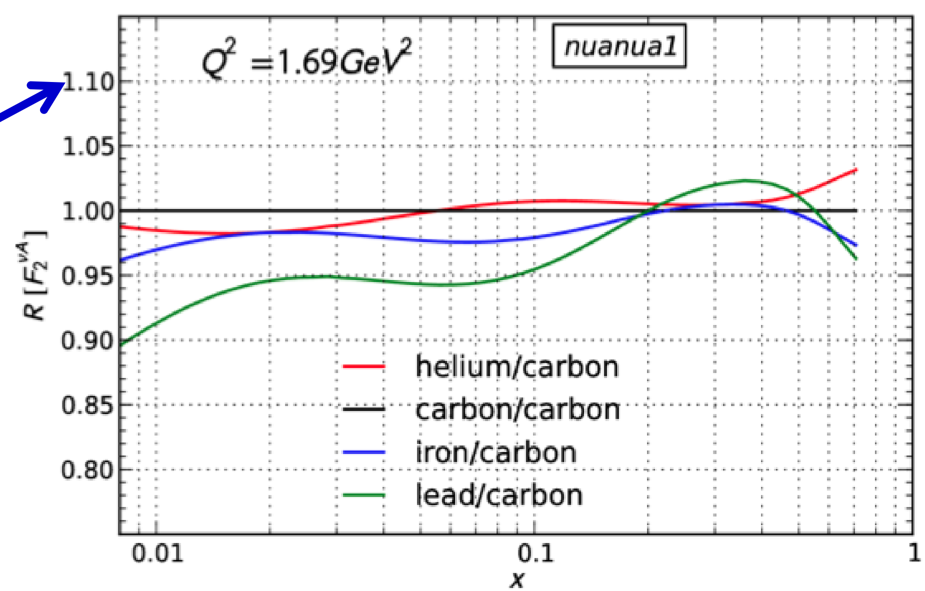
CTEQ prediction for the structure function ratios MINERνA can measure
5% to 10% effects predicted for Pb / C

Should be also studied using D targets.

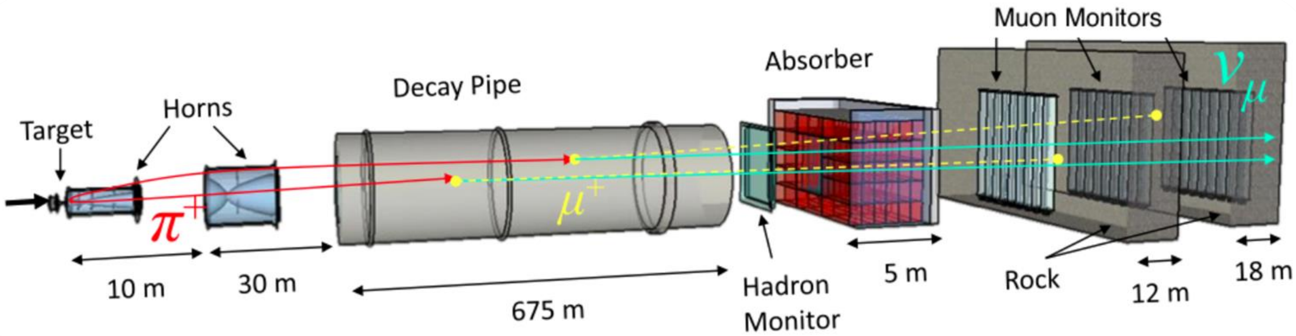
Morfin, Adv. HEP (2012) 934597



Kovarik PRL106 (2011) 122301



The NUMI Beam (Fermilab)



NuMI (Neutrinos at the Main Injector)

120 GeV protons from Main Injector, ~350 kW

90 cm graphite target

675 m decay tunnel

By moving the production target w.r.t. 1st horn and changing the distance between the horns one can modify the ν spectrum:

LE (peak ~3 GeV) $\rightarrow$ ME (peak ~6 GeV)

Flux determination

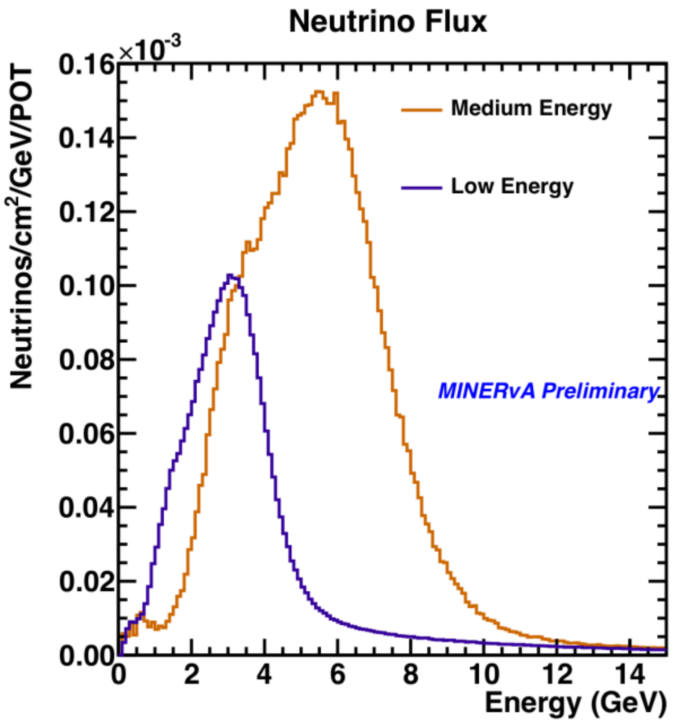
external hadron production data

ν – e elastic scattering

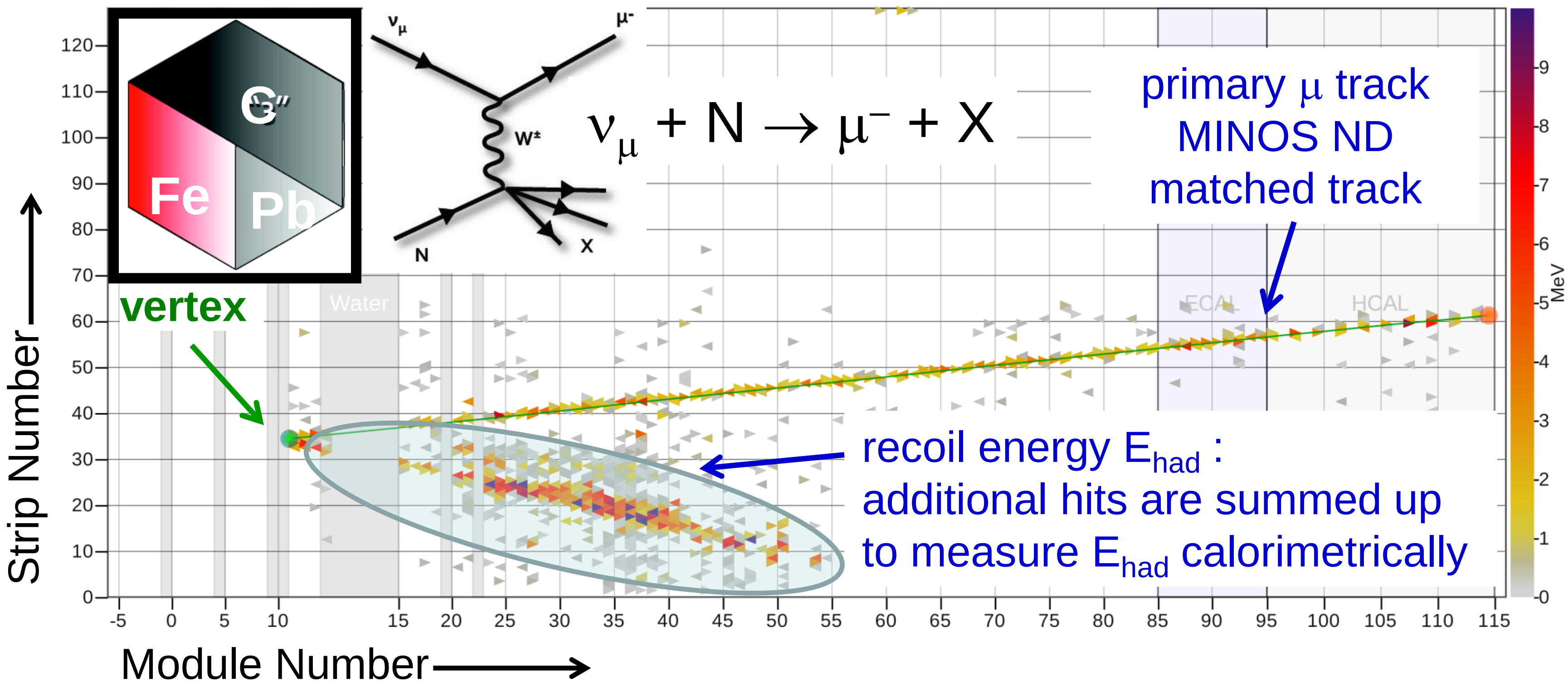
low–ν extrapolation

muon monitor data

special runs (vary beam parameters)



Event Selection and Reconstruction



Event selection criteria:

single muon track in MINERνA, well reconstructed and matched into MINOS ND

"standard cuts": $2 < E_\nu < 20$ GeV & $\theta_\mu < 17^0$ (MINOS ND acceptance)

CH_2: reconstructed vertex inside fiducial tracker region

nuclear targets: z position of vertex consistent with nuclear target

recoil energy E_{recoil} reconstructed calorimetrically

$\Rightarrow$ incoming neutrino energy E_ν: $E_\nu = E_\mu + E_{recoil}$

Recoil Energy

recoil energy E_{recoil} reconstructed calorimetrically:

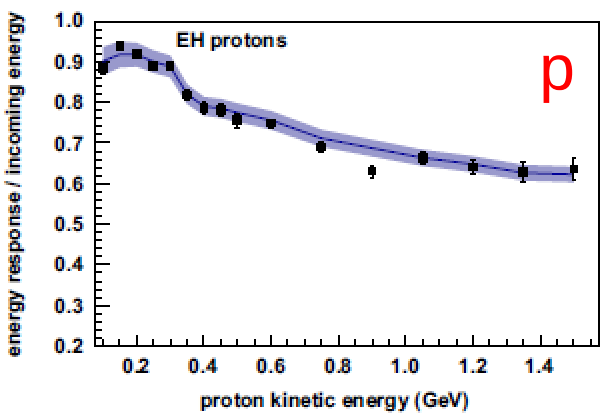
$$\boxed{\text{calorimetric } E_{recoil} = \alpha \times \sum_i c_i E_i}$$

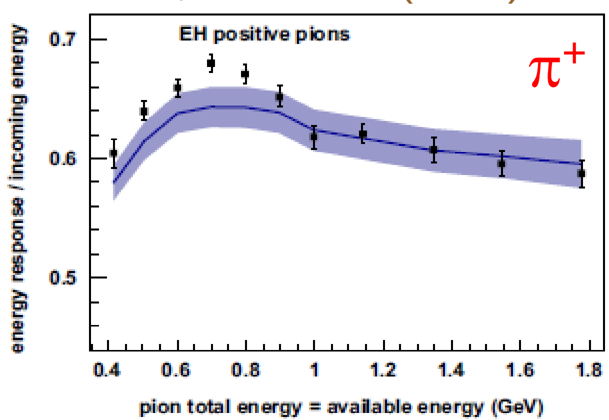
sum of visible energy, weighted by amount of passive material

MINERvA detector's hadronic energy response is measured using a dedicated test beam experiment at the Fermilab Test Beam Facility (FTFB)

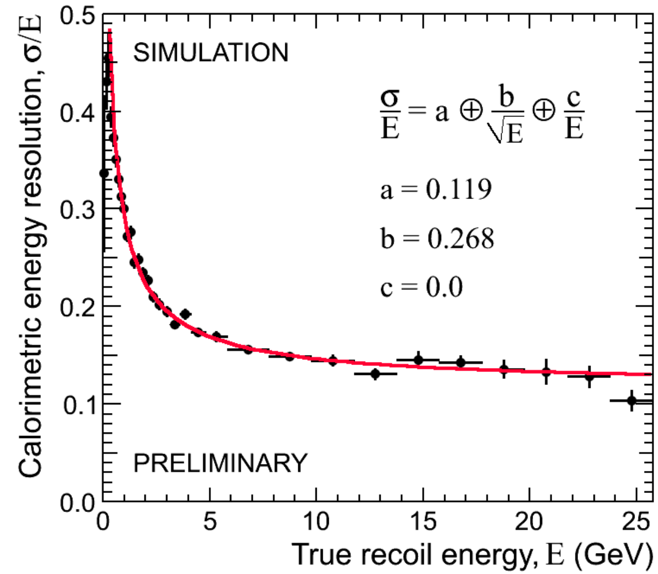
p / π^+ / π^- response measured with uncertainty < 5%

MINERνA, NIM A789 (2015) 28





Hadronic energy reconstruction uncertainty estimated from difference between test beam data and GEANT MC.

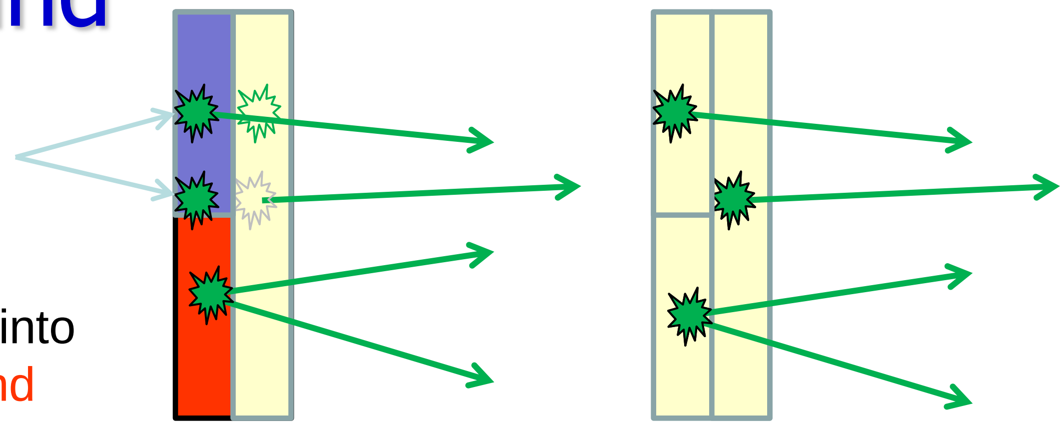


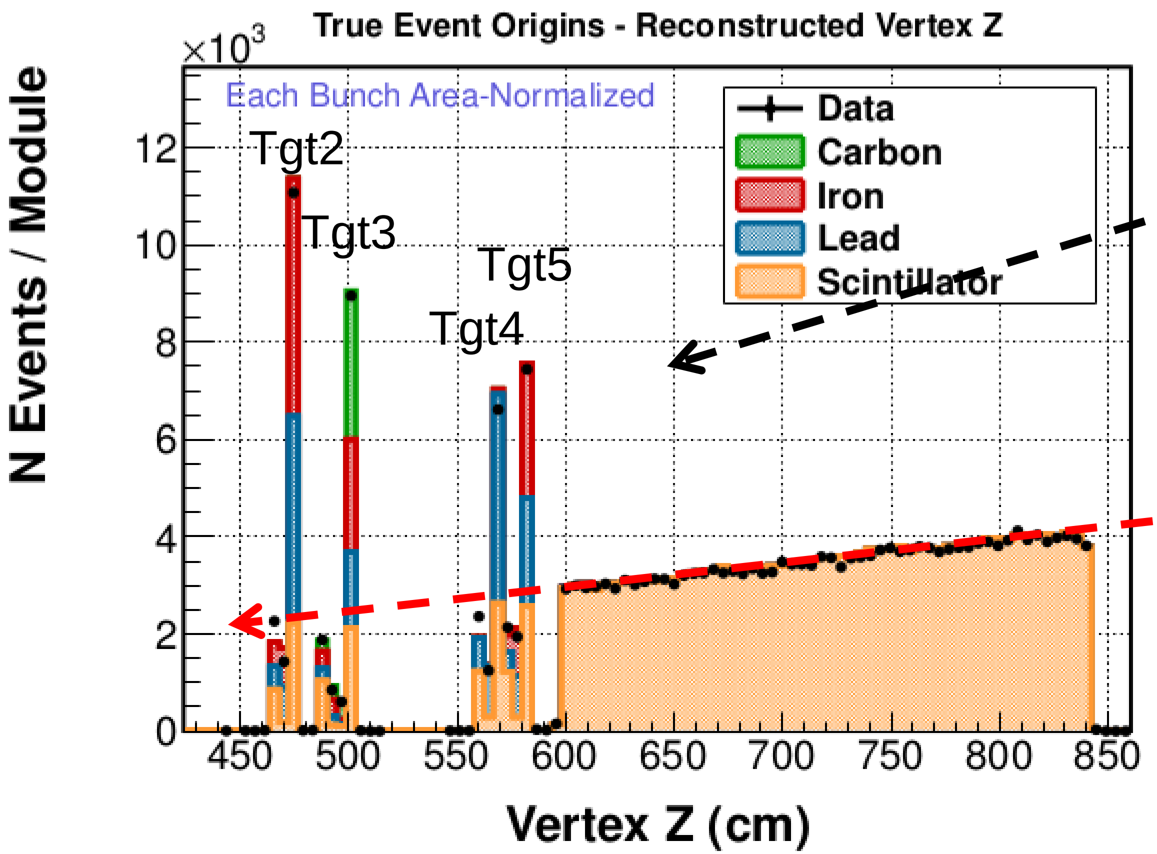
"Plastic" Background

Project the one track events to the passive target's center in *z*

This is the best guess of the vertex

Scintillator events wrongly accepted into passive target sample are background

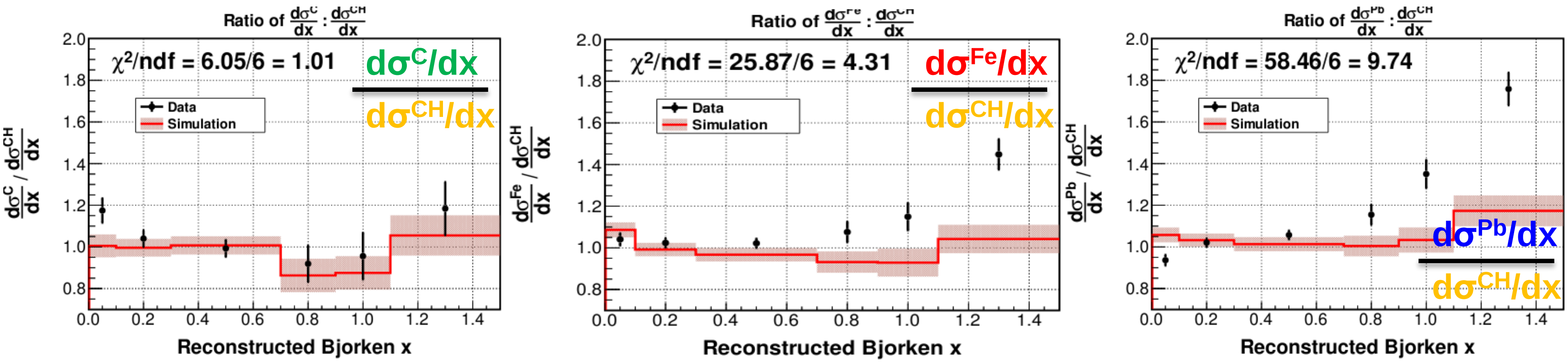




background : these peaks are at the location of the first module downstream of the passive targets

use downstream tracker modules to predict and subtract the "plastic background"

Inclusive Cross Section Ratios – $d\sigma / dx_{Bj}$



Tice et al., PRL 112 (2014) 231801

Reconstructed *x* (no correction for detector smearing)

Taking ratios removes uncertainties due to the neutrino flux, acceptance, …

At low x, *x* < 0.1, observe a *deficit* that increases with the size of the nucleus
(possibly additional nuclear shadowing in ν scattering, study more directly in DIS)

At high x, x > 0.7, observe an *excess* that grows with the size of the nucleus
(events are dominated by CCQE and resonances)

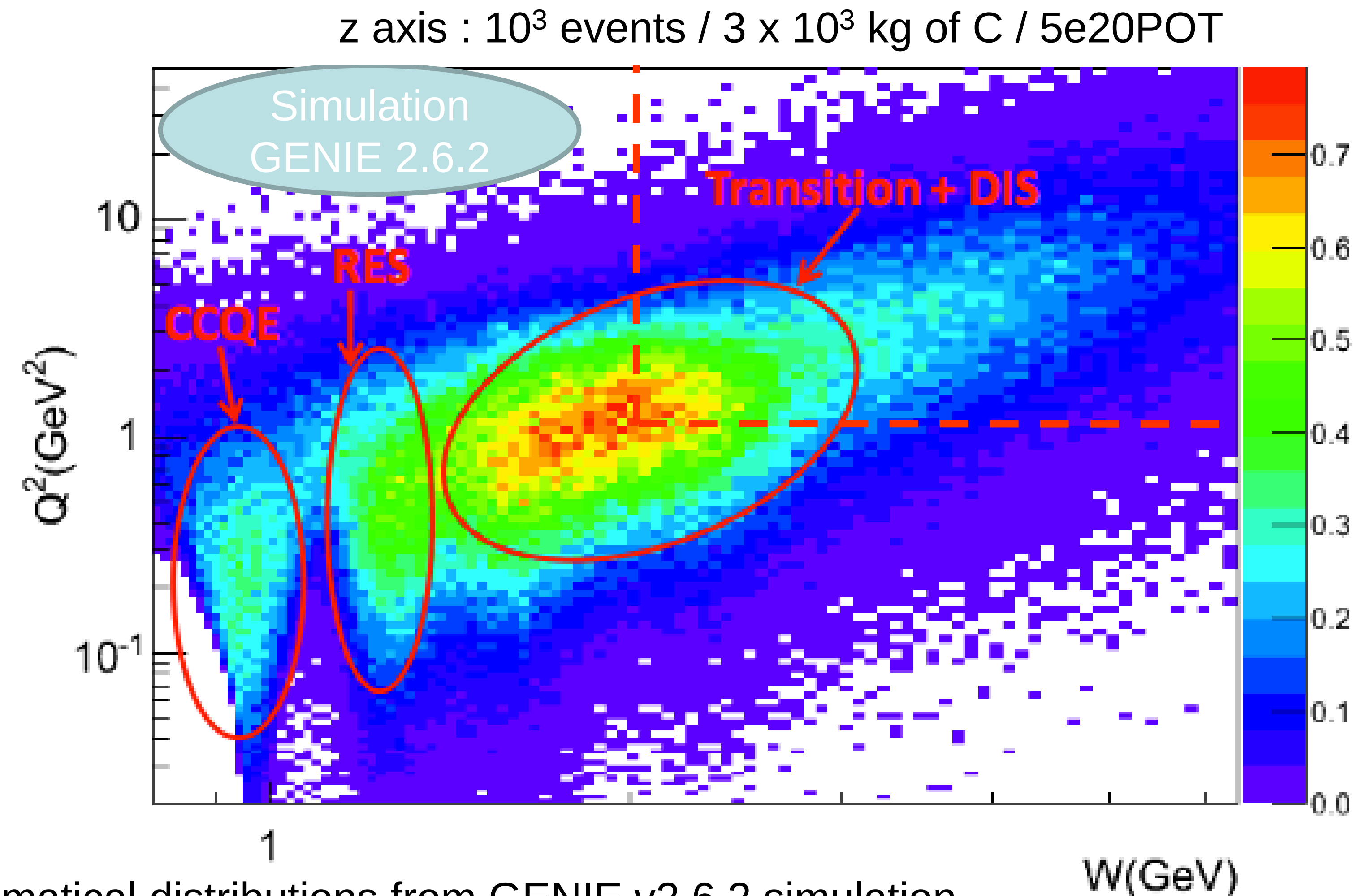
These effects are not reproduced by current neutrino interaction models

GENIE assumes an x dependent effect from charged lepton scattering on nuclei
but ν sensitive to xF_3 and also to the axial part of F_2

When studied as a function of E_ν:
no evidence of tension between MINERνA data and GENIE 2.6.2 simulations

W – Q² Kinematical Region in LE

Select DIS sample by requiring $Q^2 > 1.0\ GeV^2$ and $W > 2.0\ GeV$
(these cuts remove the quasi-elastic and resonant “background”)



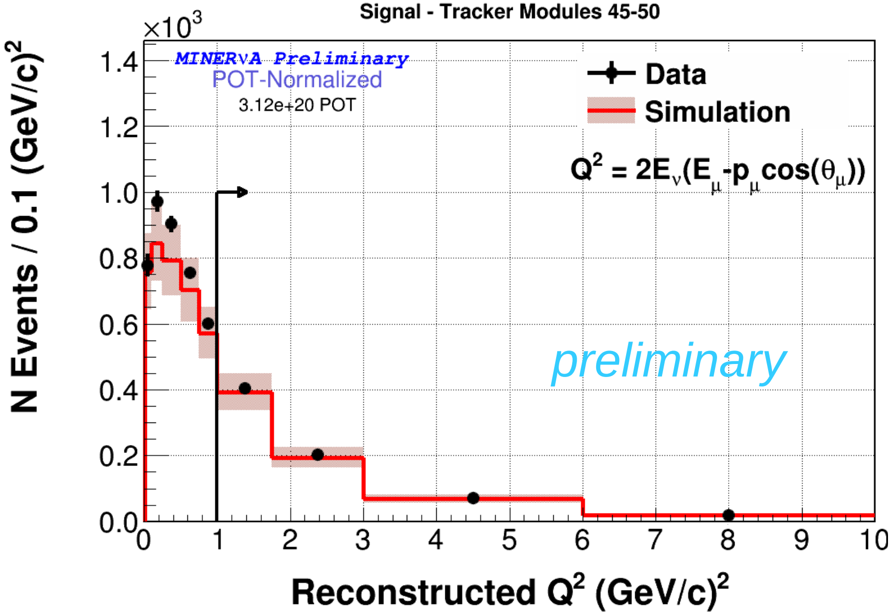
kinematical distributions from GENIE v2.6.2 simulation
events shown have muon tracked in MINOS

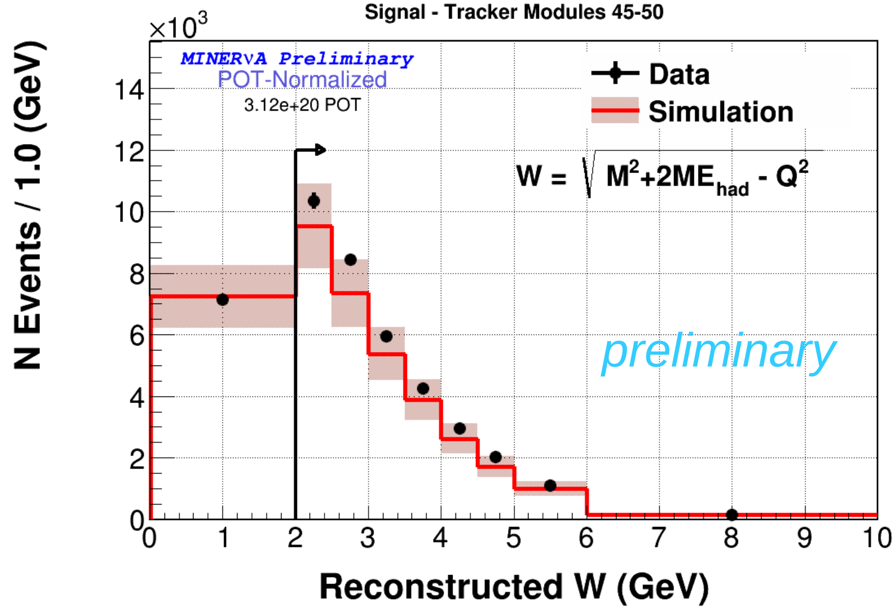
From Inclusive to DIS

Select DIS sample by requiring $Q^2 > 1.0$ GeV^2 and $W > 2.0$ GeV

These cuts remove the quasi-elastic and resonant events form the inclusive sample, and allow us to interpret our data on the partonic level.

Extend E_ν to 50 GeV : $5 < E_\nu < 50$ GeV and $\theta_\mu < 17^0$





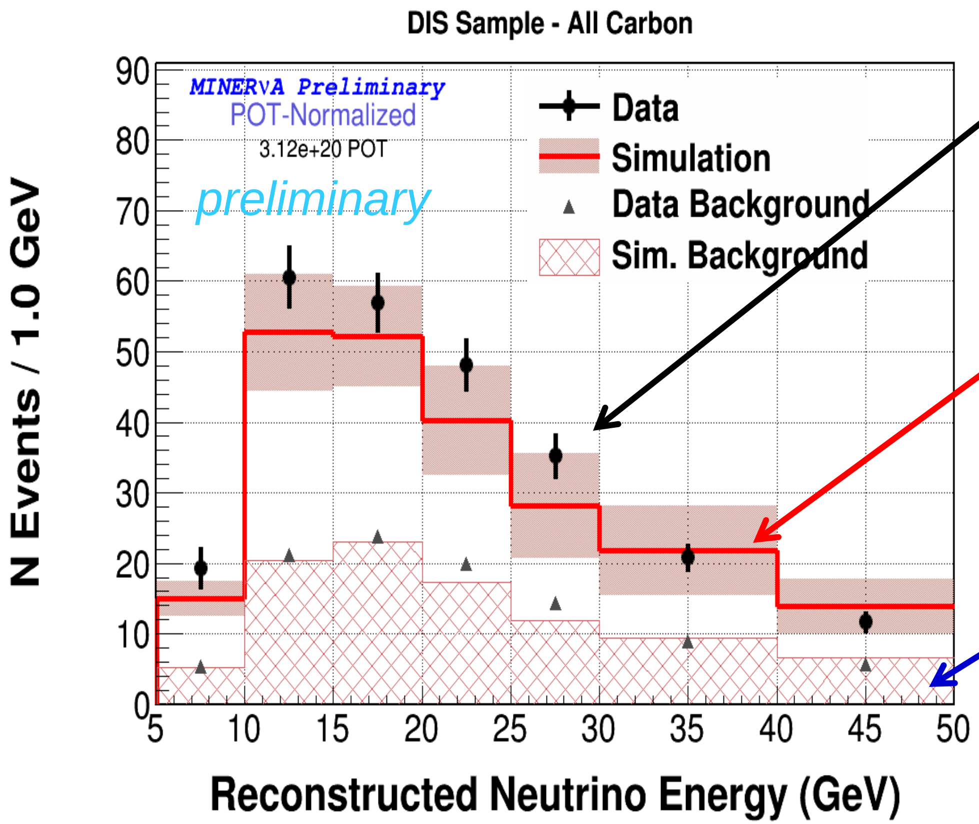
After making kinematic cuts on Q^2 and W, we are left with a background of events with *true* $Q^2 < 1.0$ GeV^2 and $W < 2.0$ GeV that smear into the sample

Estimate this background in the nuclear targets and scintillator using MC tuned to data using events adjacent to $W = 2$ GeV and $Q^2 = 1$ GeV^2

DIS Sample (E_ν)

DIS sample: $Q^2 > 1.0$ GeV^2 and $W > 2.0$ GeV
$5 < E_\nu < 50$ GeV and $\theta_\mu < 17^0$

Carbon target



Data events reconstructed in C, with non-DIS events subtracted

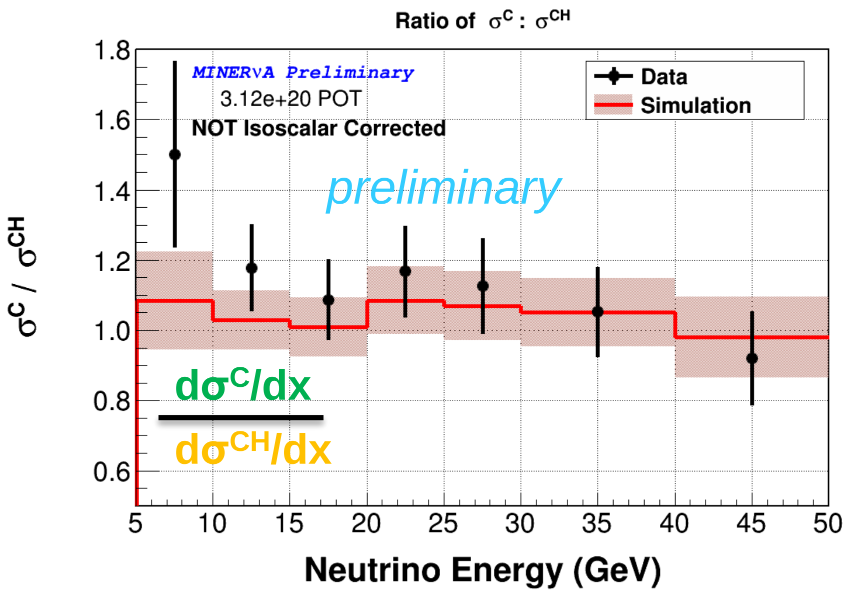
Simulated DIS events, reconstructed in C

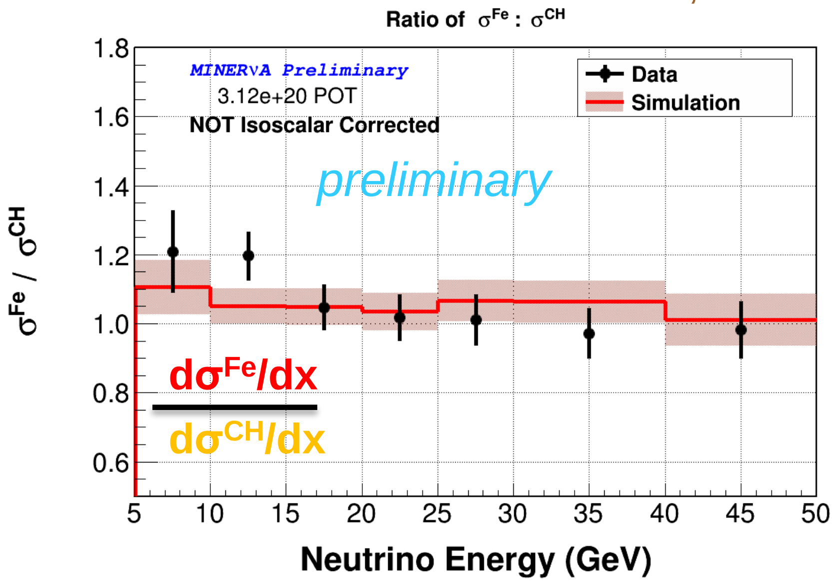
CH events in scintillator surrounding target, with non-DIS events subtracted

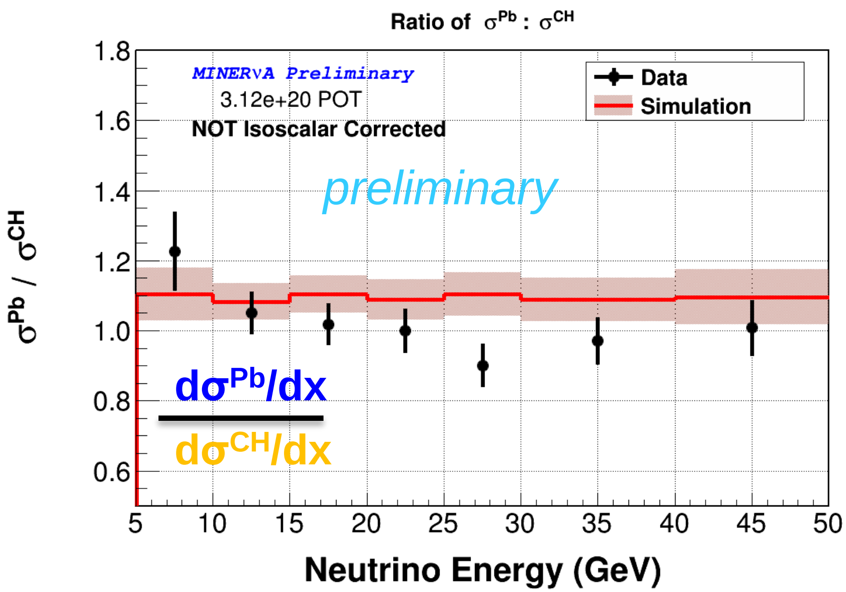
Subtract these CH events to obtain a sample of DIS on C in data and MC

DIS Cross Section Ratios – σ (E_ν)

J. Mousseau, PhD







DIS cross section ratios on C, Fe, and Pb compared to CH as a function of E_ν

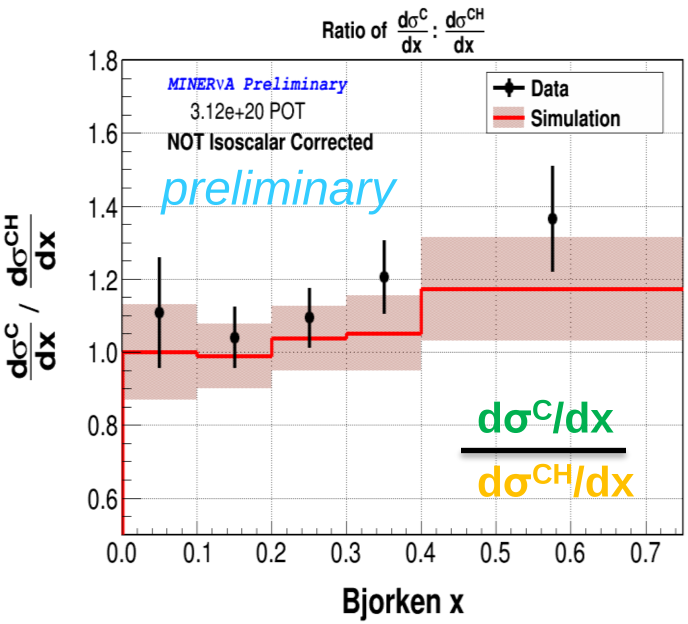
"Simulation" based on nuclear effects observed with electromagnetic probes

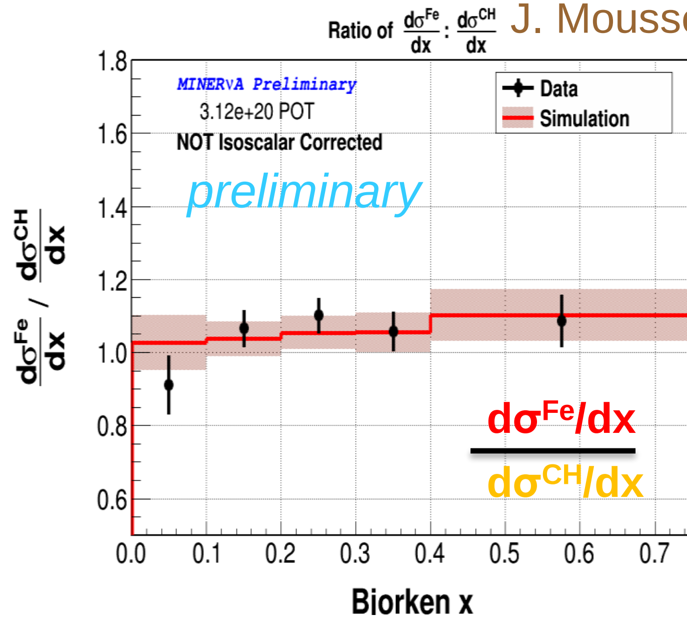
Ratios of the heavy nuclei to lighter CH are evidence of nuclear effects

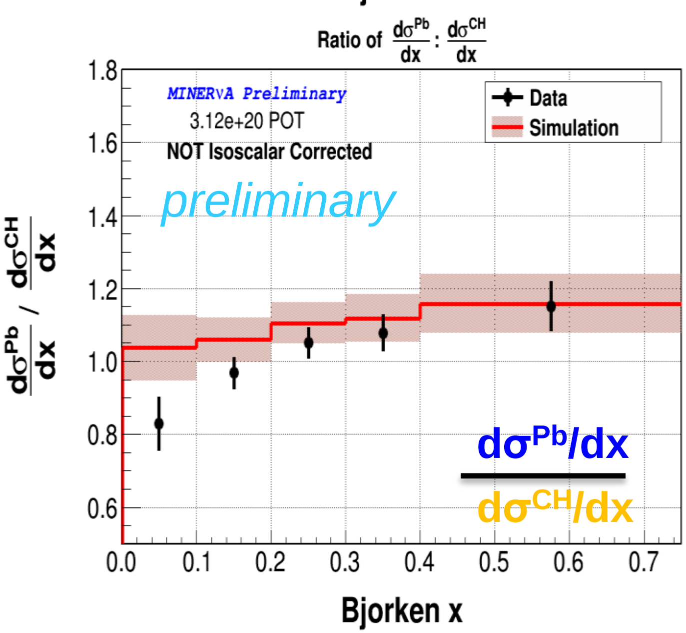
Observe no neutrino energy dependent nuclear effect

DIS Cross Section Ratios – $d\sigma$ / dx_{Bj}

J. Mousseau, PhD







Unfolded x (detector smearing)

$$x_{Bj} = \frac{Q^2}{2ME_{had}}$$

DIS: interpret data at partonic level

x dependent ratios directly translates to

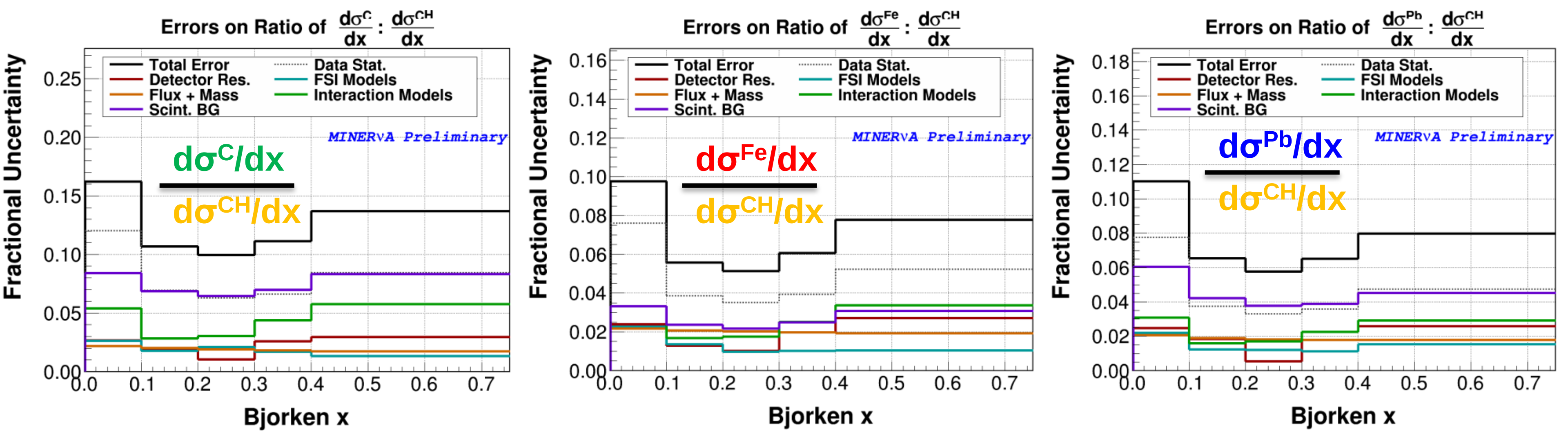
x dependent nuclear effects

(cannot reach the high-*x* with LE data sample)

MINERνA data suggests additional nuclear shadowing in the lowest *x* bin ($\langle x \rangle = 0.07$, $\langle Q^2 \rangle = 2$ GeV^2)

In EMC region ($0.3 < x < 0.7$) agreement between data and models

Cross Section Ratios Uncertainties (x_{Bj})



Taking ratios removes large uncertainties due to the neutrino flux

Uncertainties similar across different targets, all targets in same beam

$\rightarrow$ flux largely cancels

$\rightarrow$ similar acceptance and reconstruction

(however efficiency correction introduces cross section model uncertainties)

Most of the uncertainty stems from data statistics

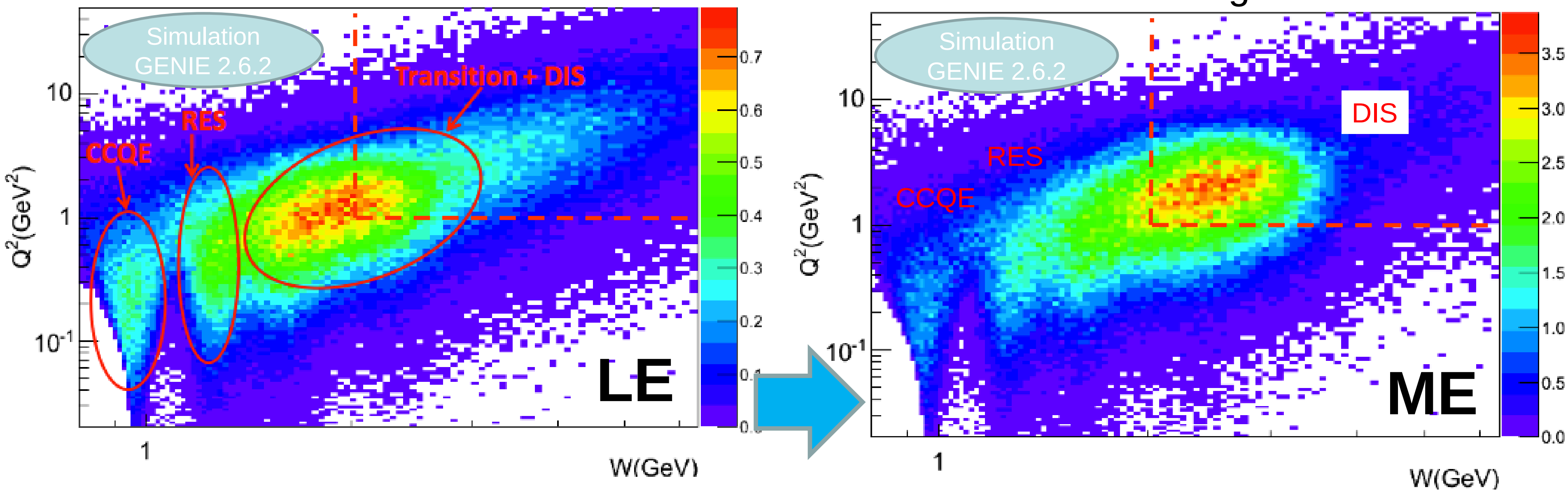
(higher intensity, higher energy ME beam will improve this substantially)

"Plastic" background subtraction introduces a larger uncertainty in *x* (not in E_ν)

Prospects for DIS with ME Beams

W – Q^2 Kinematical Region in LE and ME

z axis : 10^3 events / 3 x 10^3 kg of C / 5e20 POT



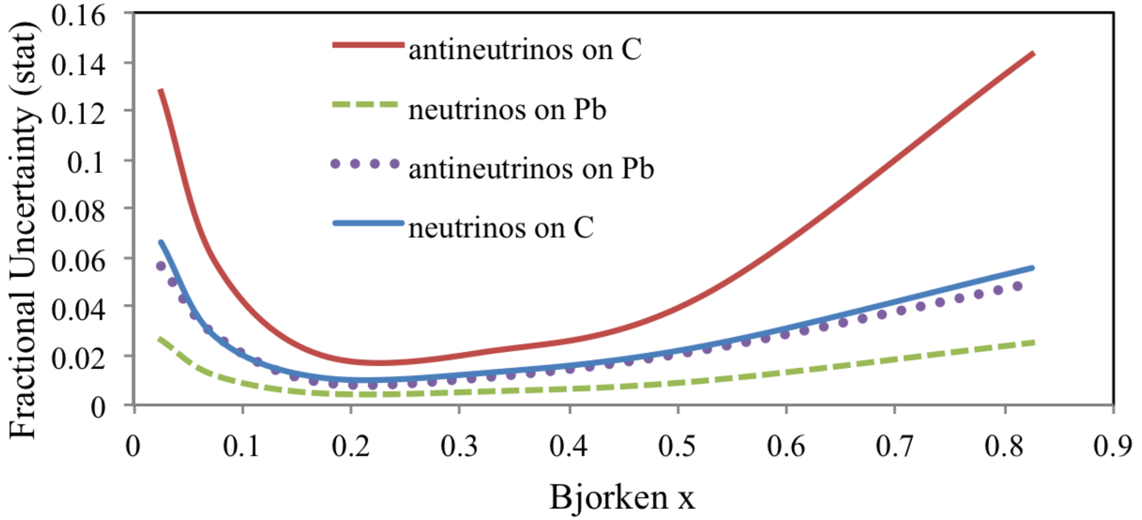
Many more neutrino interactions in DIS regime

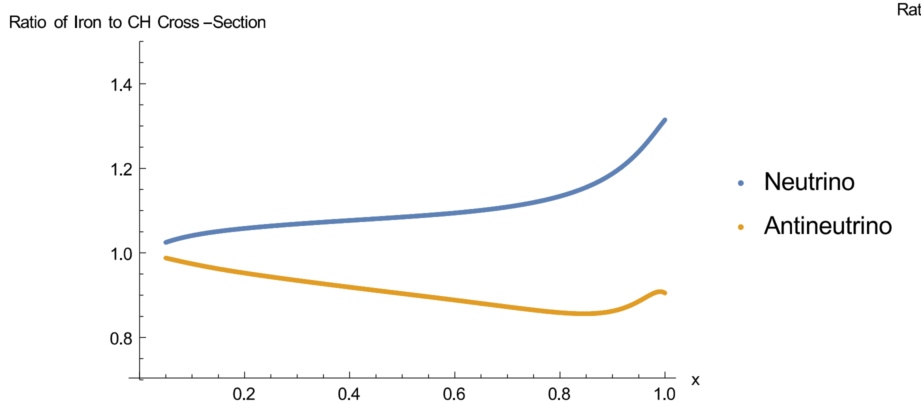
- → higher beam energy
- → increased statistics (beam intensity, energy)
- → improve on systematical uncertainties
- → structure function measurements on different nuclei
- → probe quark flavor dependence of nuclear effects

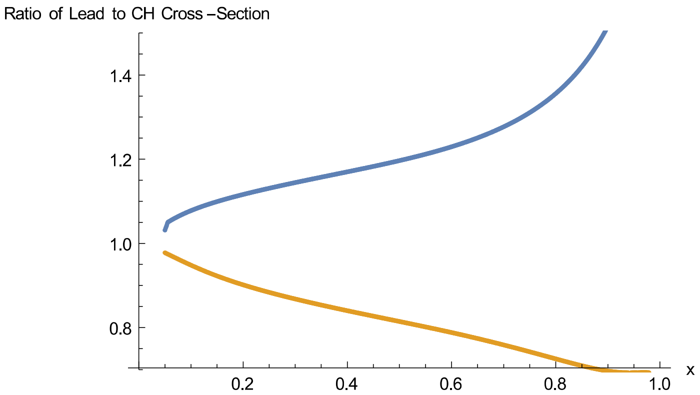
Requested 10 x 10^{20} POT in neutrino and
12 x 10^{20} POT in antineutrino mode

Physics Reach on EMC Effect

Assume 10E20 POT in neutrino mode, 12E20 POT in antineutrino mode







Prediction from Cloet model described in PRL 109, 182301

Conclusions

MINERνA attempts a systematic study of nuclear medium modifications and hadronic structure using different nuclear targets in the same detector exposed to the same neutrino beam

First measurement of ratios of neutrino cross sections on different nuclei in the DIS regime

These measurements may be interpreted directly as *x* dependent nuclear effects

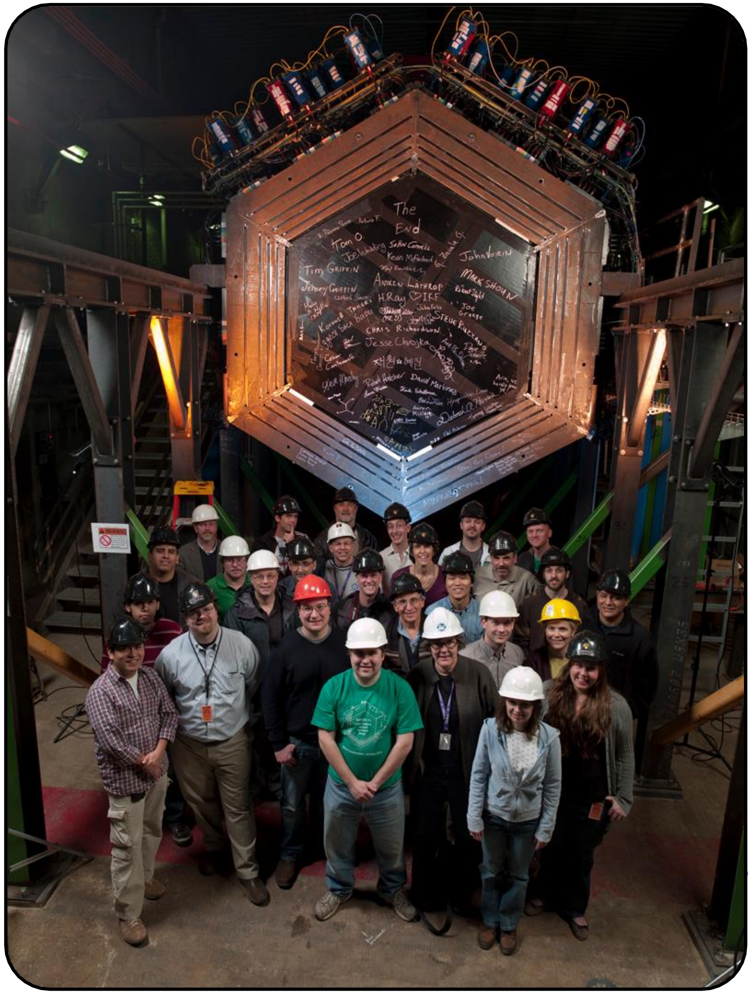
- Observe no significant E_ν dependences compared to theory
- In the EMC region ($0.3 < x < 0.7$) good agreement between data and models
  (GENIE assumes an *x* dependent effect from charged lepton scattering on nuclei)
- MINERνA data suggests additional nuclear shadowing in the lowest *x* bin
  ($\langle x \rangle = 0.07$, $\langle Q^2 \rangle = 2$ GeV^2)

Data taking with a "Medium Energy" ν beam started in fall 2013

- E_ν peak ~6 GeV, already more POT (6×10^{20}) than LE data taking
- The higher neutrino beam energy allow us to access the DIS region and study quark distributions over a broad x_{Bj} range
- Increased statistics gives nuclear target ratios for all interactions

The MINERνA Collaboration

~65 collaborators (from nucl. and part. physics)
~20 institutions



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